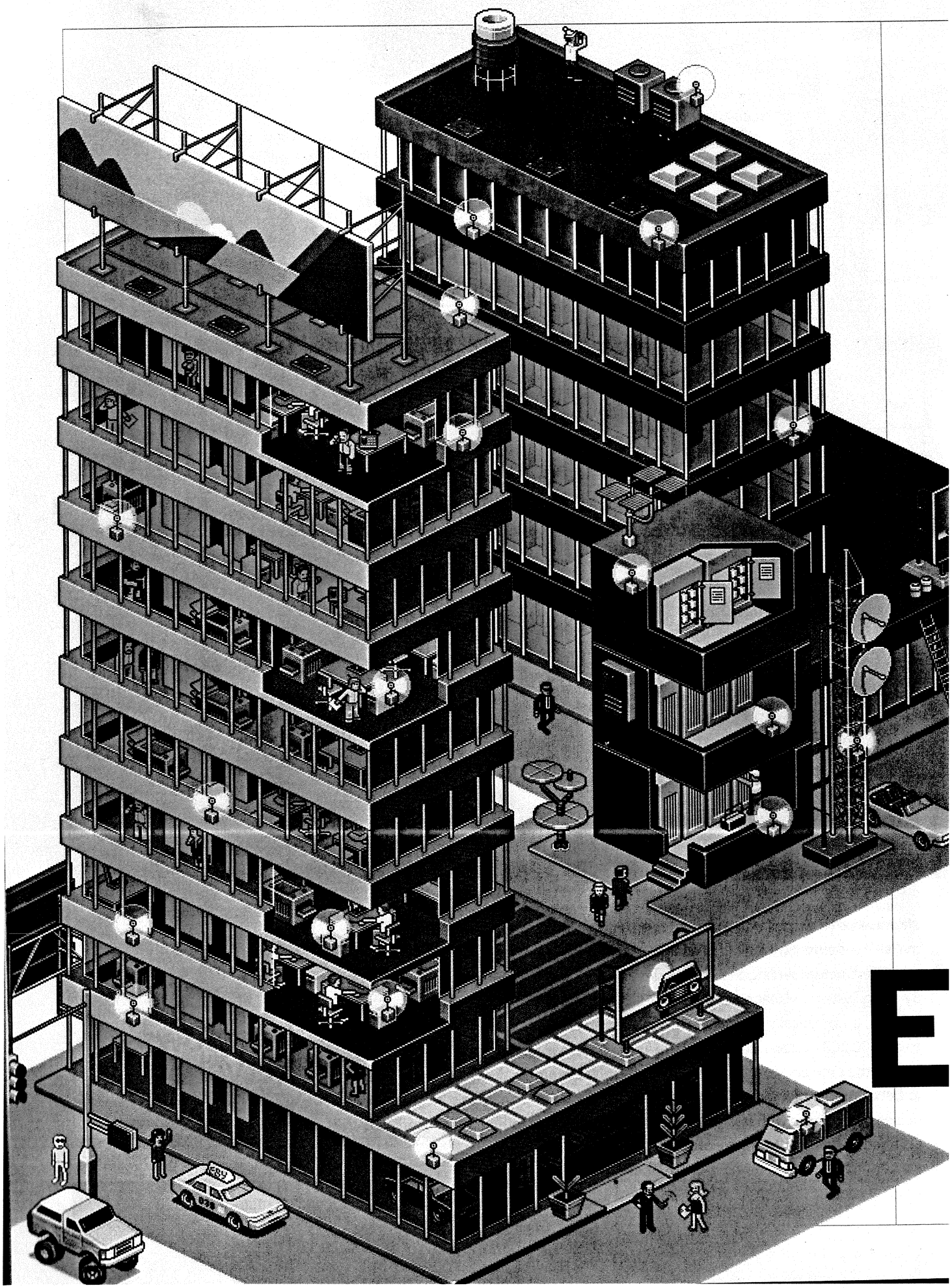
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SENSORS VERYWHERE

A 'bucket brigade' of tiny, wirelessly networked sensors someday may be able to track anything, anytime, anywhere

BY AARON RICADELA

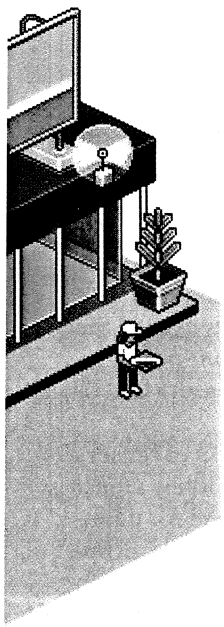

Illustration by Eboy

SOME BIG COMPANIES ARE trying to make the world—and almost everything in it—smarter.

Science Applications International Corp., the big government IT contractor known as SAIC, is developing technology for the Defense and Homeland Security departments that could use hundreds of tiny, wireless sensors packed with computing power to help secure U.S. borders, bridges, power plants, and ships by detecting suspicious movements or dangerous cargo and radioing warnings back to a command center. BP plc, the world's second-largest independent oil company, aims to knock down the cost of monitoring equipment at a Washington state oil refinery, from thousands of dollars per measurement to hundreds, by replacing big, dumb, wired sensors with wireless ones in a network.

And Hewlett-Packard is experimenting with wireless networked sensors at a warehouse in Memphis, Tenn., trying to reinvent how companies manage the flow of goods. A prototype wireless network of small video-camera sensors hooked to image-recognition software works in concert with radio-frequency identification technology to make sure inventory is put in the right place. The cameras track goods as they move through the warehouse, and those images get matched with RFID tag numbers that describe them.

Wireless sensor-network technology is at the frontier of computer networking research and could be tech's next multibillion-dollar market. Today largely

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the domain of military-funded academic research and a handful of startups spun out of these projects, wireless sensor nets could figure prominently in the plans of multinational companies and the world's largest IT vendors.

Wireless sensor devices, or "motes," package together a circuit board with networking and application software; interfaces to sensors that can detect changes in temperature, pressure, moisture, light, sound, or magnetism; and a wireless radio that can report on their findings—all powered by a pair of AA batteries. Enabled by the fusion of small, low-cost chips, low-powered radios, and the spread of wireless networking, motes are a giant leap ahead of traditional sensors that for decades have measured everything from temperature in buildings to factory machines' vibrations. Those sensors require wiring to electrical systems, which can cost $200 to $400 per sensor, and are expensive to service. Motes cost about $100 each, and are much cheaper to install. That price could drop to less than $10 in a few years, as mote components follow computing's march toward higher volumes, better performance, and lower prices.

THE UPSHOT

The next multibillion-dollar tech market may be wireless sensor networks composed of motes that can detect changes in their environment and feed data down the line to a central computer.

The easy money will probably be made creating replacement networks for monitoring companies' operations, but the potential for new apps is vast. Getting there, though, requires overcoming installation, integration, and data-analysis challenges.

Read interviews with leading researchers in sensor technology at informationweek.com/1023/qa.htm.

One breakthrough of mote technology is special "mesh networking" software that lets each device wake up for a fraction of a second when it has an interesting result to transmit, then relay that information a few yards to its nearest neighbor. So instead of every sensor transmitting its information to a remote base station, an electronic bucket brigade moves data mote by mote until it reaches a central computer where it can be stored and analyzed. Built-in logic corrects for the failure of any sensor to transmit its data by having its neighbors cover for it. The wake-up-to-transmit feature is key, since devices need to conserve power so networks can last for years unattended in the field or anywhere data gets acquired nonstop.

"This technology enabled a major advance," says Tom Sereno, a division manager at SAIC. Just 2% of the U.S. border is outfitted with ground-sensor networks that can detect illegal crossings of people or vehicles. And those sensors have shorter life spans than the wireless motes with which SAIC is developing its applications. It's using motes from Dust Networks Inc., a startup based on research originally done at the University of California at Berkeley and funded by the Defense Advanced Research Projects Agency, to help secure border crossings and other sensitive areas by combining the sensors, which can detect people, vehicles, voices, and motion, on a network with a tiny camera for snapping images. SAIC is working on similar applications that could use tiny, remote sensors on ships or in shipping containers to detect radiation from a nuclear weapon emitted during transit, or detect someone trying to sabotage a bridge. "Many of these things can be done now, but they require human surveillance," Sereno says. "This allows much of that to be automated."

The potential for cost savings over traditional wired sensors is enormous. BP installed five wireless sensors over Christmas at its Cherry Point refinery in Washington to monitor the temperature inside giant on-site fans. Using the motes will probably cost about $1,000 per measurement point—and maybe $500 within a year or two, says Harry Cassar, technology director in BP's emerging-tech group. Each connection measured the old way cost $10,000. BP achieved the $500-per-point measurement in a test last summer to measure conditions in the engine room of an oil tanker.

And BP envisions using wireless networks of sensors to monitor industrial plants and ships, remotely adjust lighting and heat in office buildings, test soil for pollutants, and detect whether chemicals are stored properly. "Wireless mote technology has got applications in almost every part of our business," Cassar says. "We're not going to be putting in tens of these devices, or even hundreds. Ultimately, it's going to be thousands."

The technology also is gaining interest because sensor nets can be used with RFID to more cheaply identify and track goods, machinery, or hazardous chemicals. "We see IT expanding out of data centers and into buildings and factory floors," says Salil Pradhan, HP's chief technology officer for RFID. The academic world has been obsessed with making RFID tags and sensors cheap and power-efficient, Pradhan says, and the market for "multisensor fusion" is going to be huge.

HP isn't the only organization trying to couple RFID and motes. At Edwards Air Force Base in Southern California, NASA is preparing to use smart sensors and RFID tags to monitor hazardous chemicals (see "RFID Lets NASA Monitor Hazardous Materials," Jan. 10, p. 21; *informationweek.com/1021/rfid.htm*).

Most pilot tests so far have been modest, but companies including Boeing, Chevron-Texaco, Honeywell, Motorola, and Siemens all are exploring the technology. In December, Japanese tech conglomerate Fujitsu Ltd. disclosed a research agreement with Xerox subsidiary Palo Alto Research Center to explore equipping buildings with networked earthquake sensors, outfitting cars with wireless sensors to avoid collisions, and more. At a summit of world leaders in Jakarta, Indonesia, following December's tsunami, plans for building a network of sensors in the Indian Ocean to warn of undersea earthquakes were at the agenda's fore. But the fast money in the next few years probably will be made delivering wireless sensor nets to big companies as cheaper replacements for routine maintenance and monitoring of operations, such as controlling lighting or providing security around a building or at a border.

Intel, for example, has outfitted an Oregon chip-fabrication plant with 200 wireless sensors that constantly monitor vibration levels on some of the factory equipment and report when a measurement falls out of spec. The effort covers only a fraction of the plant's 4,000 measurable parts but has replaced some rounds by a technician who gets to each machine only every two or three months, Intel Research associate director Hans Mulder says.

General Electric Co. this month completed a test of sensor-outfitted shipping containers that can detect tampering, and it's developing products that could use mesh networks to secure apartment buildings and industrial areas. And Bechtel Group Inc., the largest U.S. engineering and construction company, may within a year or two start testing sensor nets that use a new standard, IEEE 802.15.4, that lets motes self-assemble into a network without programmers specifying what route the data takes. Bechtel has built wireless sensors into projects such as London's subway system and expects the technology to have applications in smart buildings, defense contracts, and chemical plants, infrastructure architecture manager Fred Wettling says. "We see this just starting to take off."

By 2008, there could be 100 million wireless sensors in use, up from about 200,000 today, market-research company Harbor Research says. The worldwide market for wireless sensors, it says, will grow from $100 million this year to more than $1 billion by 2009.

If the technology is to lead to new applications that can open up new markets, sensors' data has to be readily consumed by widely used business software. More industry standards are needed so software vendors have common ways of pulling sensor data from networks that contain sensor nodes of varying intelligence, made by different manufacturers. Researchers also are working on embedding software into sensors to make them more selective about what data is transmitted back to

RESEARCH BOOST: Government funding spurs progress

Remote sensors that measure everything from the temperature in buildings to vibrations of machinery in a factory have been around for decades. But a stream of government funding in recent years has accelerated progress.

"Government funding really primed the pump," says Kris Pister, an electrical engineering and computer-science professor at the University of California at Berkeley and chief technology officer at startup Dust Networks Inc., which he founded in 2002. Sensor network research got a boost in 1997 when Pister, who'd been working for several years to combine microelectrical mechanical systems technology, traditional sensors, and wireless communications, petitioned the Defense Advanced Research Projects Agency to fund his research into "smart dust"—tiny sensor devices that could eventually be shrunk to the size of a grain of rice. David Tennenhouse, now a VP at Intel, was the Darpa exec who provided initial funding. David Culler, a Berkeley computer-science professor who later worked for Intel, wrote the software.

At the University of California at Los Angeles, computer-science professor Deborah Estrin in 2002 established the Center for Embedded Networked Sensing, and has secured a 10-year, $40 million grant from the National Science Foundation to study wireless sensor networks. "Darpa started seeding the original university research," Estrin says. "Now it's being pushed by the science community." Other universities researching the area include MIT and the University of Michigan.

Government agencies such as the Energy and Transportation departments have been funding sensor-net research as well. The Transportation Department has funded studies at automakers to put sensors on cars and trucks to help them avoid collision. The department also is exploring roads, bridges, and runways with networks of sensors that could broadcast information about driving or aircraft landing conditions under a program called Intelligent Transportation Systems.

In December, the Federal Communications Commission set aside a slice of broadcast spectrum for a future "collision-avoidance system" that could transmit signals from highway sensors and warn drivers about other cars on the road. The Transportation Department is testing the technology at an intersection in McLean, Va. —**AARON RICADELA**

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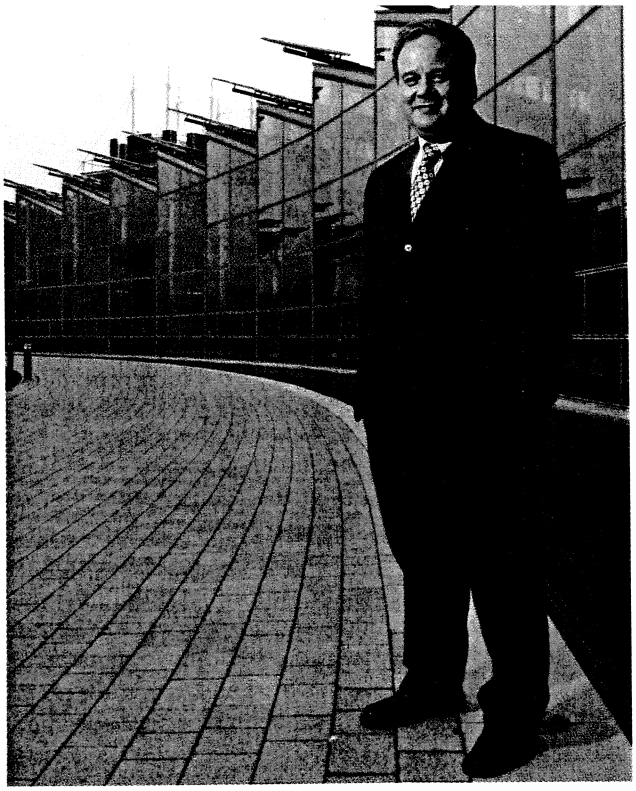
base or to condense information to conserve even more power. Without that capability, large sensor networks could quickly overwhelm themselves, and back-end computers, by draining bandwidth and battery power trying to transmit a flood of data from the field.

But there will still be plenty of data to analyze, and big tech vendors and consultants are going after the emerging market for computer systems and software to do just that. HP, IBM, Intel, Microsoft, SAP, and Sun Microsystems all have recently formed research or product groups to refine and commercialize the technology. For example, SAP is working with Intel and other companies to make sure its applications can consume and analyze the sensor data. SAP and BP also are participants in a European Union-funded project scheduled for this year to build "smart items" such as chemical barrels that broadcast warnings when they're inappropriately stored.

The tech giants already cede the mote market to companies such as Dust, which last year landed funding from the CIA's venture-capital arm, In-Q-Tel. Ember Corp., a startup based on work at MIT, has attracted an investment from Ethernet inventor and 3Com Corp. founder Bob Metcalfe. And Crossbow Technology Inc. has been selling to BP and supplying Intel's projects. "We're not competing with startups," HP's Pradhan says. The big IT vendors want to supply huge volumes of chips for motes, then sell installation services, but their primary goals are to develop new applications for sensor nets and sell software and consulting services. One big problem to solve: the lack of software tools that can program whole networks of sensors in one shot.

"For every dollar the big systems integrators and IBM make on sensors and installation, there's $10 to be made on the management of the data that comes out," says Kris Pister, a professor of electrical engineering and computer science at UC Berkeley, who founded Dust in 2002 and serves as its CTO. IBM, which plans to spend $250 million during the next five years on the technology and has created a "sensors and actuators" business unit, predicts wireless sensor nets could represent a $6 billion overall market by 2007, with the bulk of profits from software that helps the devices better communicate and lets customers interpret data from them.

"Sensors are just a part of an ecosystem of wireless devices," says Feng Zhao, a senior researcher at Microsoft who joined the company last year from PARC to head up a new sensor nets research group on Microsoft's Redmond, Wash., campus. His test bed is parking level P2 of building No. 112, where a handful of sensors detect the size, speed, and magnetism of everything that crosses the garage's threshold, triangulating data from video images and magnetic readings of staffers' cars. At a remote PC, a researcher can analyze the day's traffic by logging



BP aims to have thousands of wireless motes in service, says Cassar, technology director in the emerging-tech group.

Brent Stirton/Getty Images

on to a Web site and posing queries using standard Web-programming techniques. It works in a restricted scenario and with research prototypes, Zhao says, but "we need to figure out how to organize these systems and develop interesting applications for them" for real-world use. "For all these apps, writing software is very challenging. That will probably be a stumbling block between sensors and killer apps."

"It's kind of like the beginning of the Arpanet days for this sensor-net technology, where there's no killer app yet," says Teresa Lunt, manager of the computer-science lab at PARC. A PARC research project called "smart matter" aims to embed sensors in the environment, and the center has done experiments with Darpa funding, including using sensor nets to track a mock military tank based on its signature sounds. At current prices, though, minus the sensors attached to them, wireless motes are still impractical for most large networks, Lunt says. "But they've served as a placeholder people can use to envision applications with the understanding that they'll be replaced by better technology," she says. "They've been igniting people's imaginations."

Sensor proponents predict a day when superhighways will be salted with motes that help drivers avoid collisions, bridges report when they're seismically stressed, and networks of video cameras pick terrorists out of a crowd. That's a long way from turning down the air conditioning when it gets too hot.

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